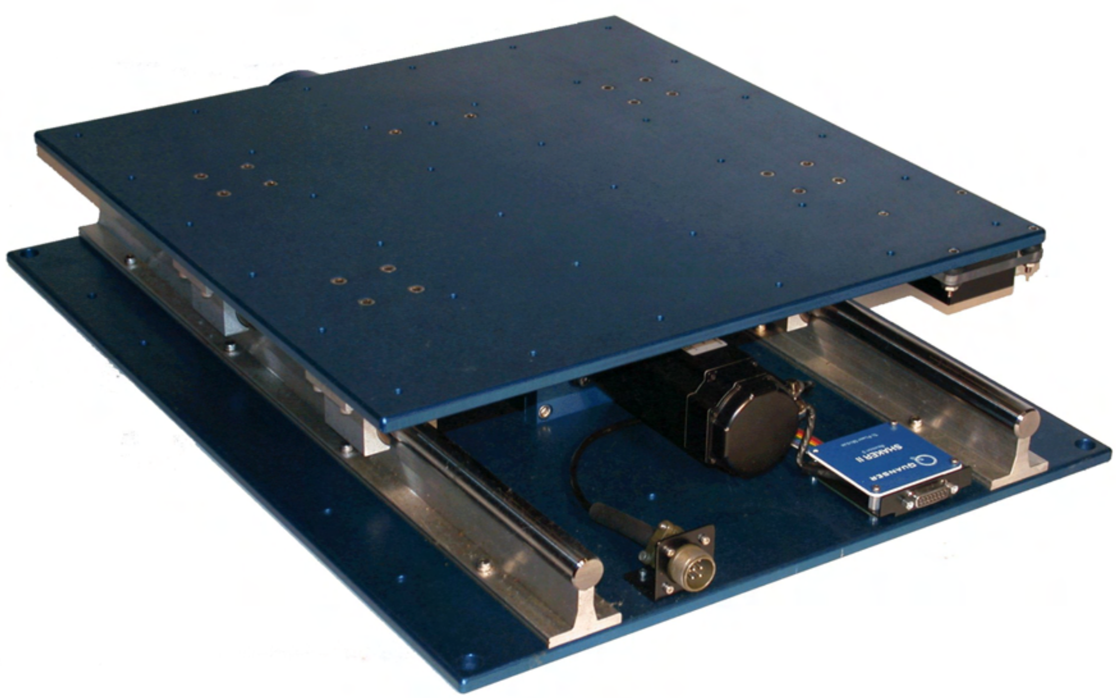
Specialty Plant: Shake Table II

Position Control and Earthquake Analysis

Shake Table II



User Manual

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Quanser Shake Table II User Manual

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1. Introduction

The Quanser Shake Table II shown in Figure 1 is an instructional shake table device that was originally developed for the *University Consortium on Instructional Shake Tables* (UCIST). It can be used to teach structural dynamics, vibration isolation, feedback control, and various other topics for mechanical, aerospace, and civil engineers.

The top stage of the shake table is driven by a powerful motor that allow it to achieve an acceleration of 2.5 g when up to 7.5 kg of mass is mounted. The stage rides on two ground-hardened metal shafts using linear bearings which allows for smooth linear motions with low path deflection. When starting from center the stage is capable of moving 7.62 cm, or 3-inches, on each side. It therefore has a total travel of 15.24 cm. In order to move the top platform at a high acceleration, a robust ball-screw and motor assembly is used. The high-powered 400 Watt motor is a 3-phase brushless DC actuator. The motor contains an embedded high-resolution encoder that allows the position of the stage of be measured with an effective linear resolution is 3.10 μm. An analog accelerometer is mounted on the Shake Table II platform in order to measure the acceleration of the stage directly.

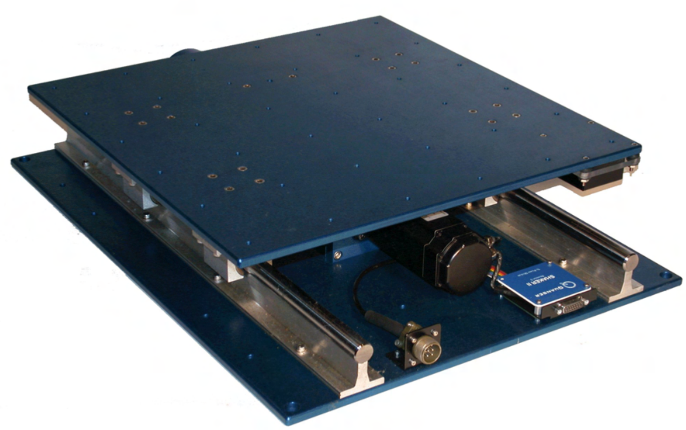

Figure 1: Shake Table II system.

The main devices used to run the shake table is depicted in Figure 2. The entire is comprised of a Universal Power Module (UPM), a data-acquisition (DAC) card, a PC running the WinCon control software, and the Shake Table II itself. Consider for example the signal transitions between the system components when the user wishes the Shake Table II stage to track a sine wave and read the resulting acceleration. Using WinCon on the PC, the user specifies the amplitude and frequency of the sine wave. The sine wave is the user-specified desired or command position of the stage. The current needed to move the stage at the desired sine wave position is calculated in WinCon and sent through the analog output channel of the data-acquisition board to the UPM device. The power amplifier in the UPM amplifies the current and drives the motor. The table moves back and forth at the position and frequency of the commanded sine wave. The resulting displacement and acceleration of the stage are

measured by the on-board encoder sensor and the accelerometer sensor. The encoder and accelerometer are connected to the DAC board and their signals can be displayed and processed further in WinCon. Plotted data can be also be saved for later analysis.

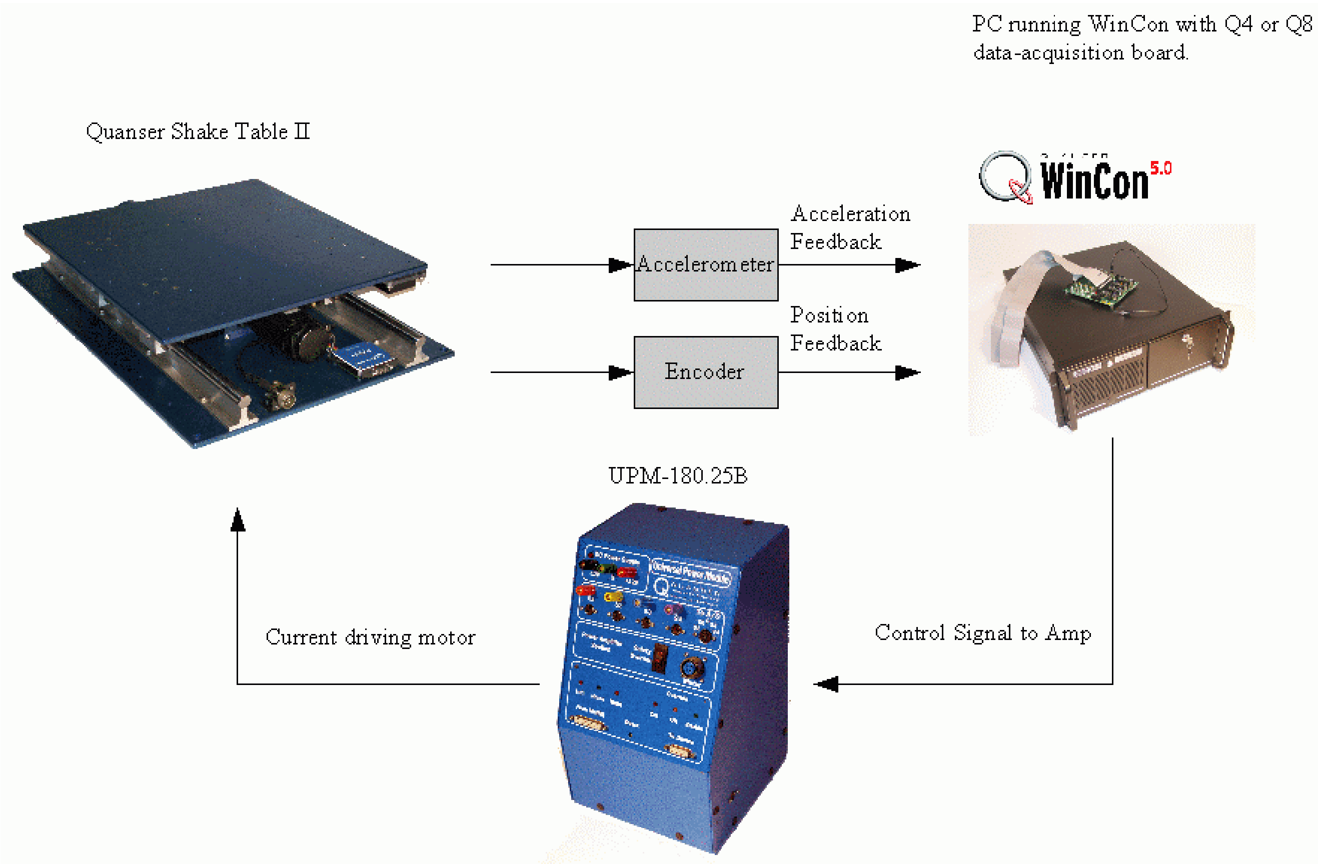

Figure 2: Overview of major system components.

Section 3 describes the various devices composing the Shake Table II system and gives some specifications. The wiring procedure for a typical setup is explained in Section 4. In Section 5, the procedures to run the basic experiments on the shake table are described. It explains, for instance, how how to make the top stage of the shake table track a sine wave. Section 6 goes into more detail and explains how to design custom shake table controllers. For example, the user may wish to have the shake table track a sawtooth wave instead of a sine wave. This is not already supplied and would have to be created. In addition, Section 6 discusses how to download recorded earthquake data from the Internet and replay them on the shake table.

2. Prerequisites

To successfully run a Shake Table II controller, the prerequisites are:

i. To be familiar with your Shake Table II main components (e.g. actuator, sensors), your data acquisition card (e.g. Q8), and your power amplifier (e.g. UPM), as described in this manual, References [1], and [2], respectively.
ii. To be familiar with WinCon enough to open a WinCon Project and run it to control the position of the shake table device. This is explained in this manual.
iii. For the *advanced* configuration (to be explained later), users need to be familiar in using WinCon to control and monitor the plant in real-time and in designing their controller through Simulink. Reference [3] provides full details of the WinCon software.

3. System Description

The main components that compose the Shake Table II device are identified in Section 3.1 and those components are described in Section 3.2. See Section 3.3 for a listing of the Shake Table II specifications.

3.1. Component Nomenclature

Table 1 provides a list of all the principal elements composing the Shake Table II system. The components are identified on the Shake Table II system in figures 3 and 4 through the corresponding identification (ID) numbers.

ID #	***Description***	***ID #***	***Description***
1	Stage	**9**	Sensor Circuit Board
2	Base Plate	**10**	Left Limit Sensor
3	Brushless DC Motor	**11**	Home Position Sensor
4	Lead screw	**12**	Right Limit Sensor
5	Ball nut	**13**	Motor Leads Connector
6	Manual adjustment.	**14**	Motor Encoder & Hall Sensors Connector
7	Hardened Steel Guide Rail	**15**	Accelerometer
8	Linear bearing block	**16**	Accelerometer Connector

Table 1: Component nomenclature.

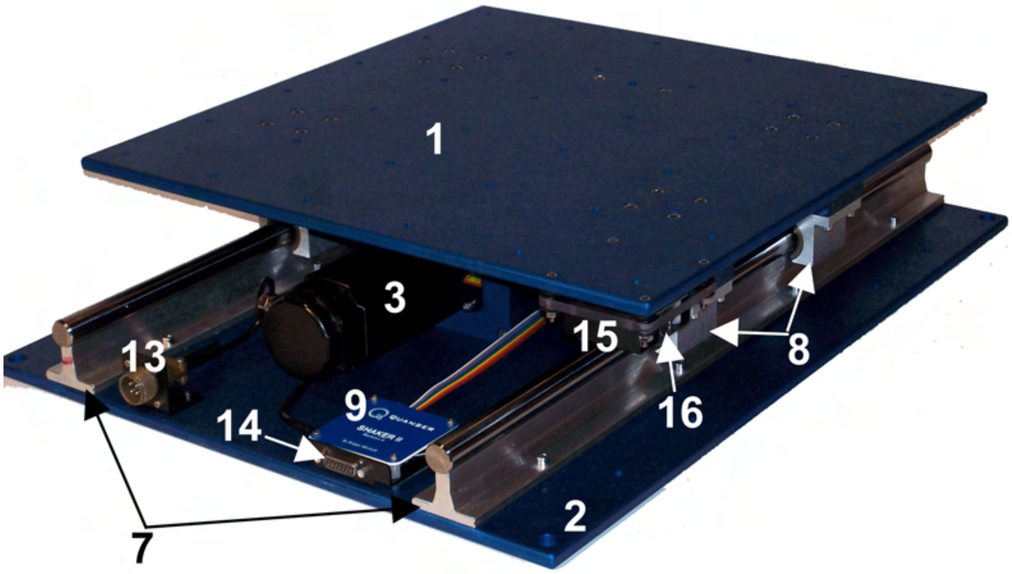

Figure 3: Top view of Shake Table II components.

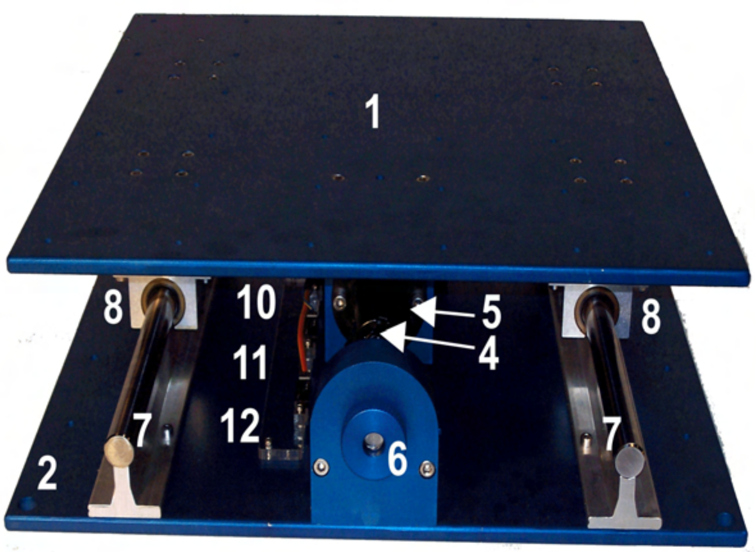

Figure 4: Front view of Shake Table II components.

3.2. Component Description

This section describes some of the components listed in Table 1 above.

3.2.1. Stage (Component #1)

Table 2 below lists and characterizes the overall dimensions of the 18-inch by 18-inch top stage or platform of the Shake Table II system. It is labeled with ID #1 and shown in figures 3 and 4. As illustrated, the top plate has many screw holes that can be used to fasten structures and other objects such as the Quanser AMD-1 and AMD-2 structures (see Reference [5] and [6]).

Description	Value	Unit
Length	0.457	m
Width	0.457	m
Thickness	0.0097	m

Table 2: Dimensions of the top stage.

3.2.2. Bottom Plate (Component #2)

The bottom support plate of the Shake Table II is pictured in figures 3 and 4 by ID #2 and its dimensions are given in Table 3. The metal shafts as well as the ball-screw are all fastened onto this plate. Notice that there are four large screw holes at each corner as well as smaller screw holes along the sides of the plate. These can be used to fasten the shake table onto a ground floor support to prevent the shake table system from moving, or at least reduce the amount of vibration. Although this is not necessary, it is recommended in order to yield more precise results when, for instance, measuring acceleration.

Description	Value	Unit
Length	0.609	m
Width	0.457	m
Thickness	0.00124	m

Table 3: Dimensions of the bottom plate.

3.2.3. Brushless DC Motor (Component #3)

The Shake Table II incorporates a Kollmorgen AKM24 brushless 3-phase DC Motor, as shown in Figure 3 by ID #3. The motor has a power of 400 Watts. It is connected to a ball-screw that and drives the ball nut assembly fastened to the bottom of the shake table platform. The brushless commutation is ensured through three hall sensors with a phasing of 120 degrees. Some of the motor specifications are included in Table 4. More detailed motor specifications are available in Reference [4].

3.2.4. Lead Screw (Component #4)

The lead screw, shown by ID #4 in Figure 4, circulates through a ball nut, component #5 in Figure 4, that is attached to the bottom of the shake table stage and is rotated by the motor. The lead screw has a pitch of 0.50 inches. Thus the shake table stage moves 0.50 inches, or 1.24 cm, per single ball-screw revolution.

3.2.5. Encoder

The encoder is embedded inside the DC motor and is used to measure the linear position of the stage. It cannot be identified externally. The motor encoder has a resolution of 2048 lines per revolution. In quadrature mode this gives 8192 counts per full rotation motor shaft rotation. The effective resolution, i.e. minimum linear position that can be detected, of the stage displacement is 3.10 μm.

3.2.6. Linear Bearing Block (Component #8)

For smooth motion, the stage is fitted with low friction linear ball bearing blocks, shown by ID #8 in figures 4 and 5, that glide on two ground hardened shafts, identified by component #7 in figures 3 and 4.

3.2.7. Limit Switches (Components #10, 11, and 12)

These *Left*, *Home*, and *Right*, proximity sensors are shown in Figure 4 with ID # 10, 11, and 12, respectively. The *Left* or *Right* limit switch get triggered when the top stage moves close to the left or right mechanical range. Similarly, the *Home* sensor is set to high when the top stage is at the mid-stroke or center position. These sensors are used by UPM-180-25B to deactivate the power amplifier for safety as well as for calibrating the stage to its center position.

3.2.8. Accelerometer (Component #15)

An accelerometer is mounted underneath the top stage of the Shake Table II that measures the acceleration in both the x and y directions. It is shown with ID #15 label in Figure 3. The analog sensor is calibrated such that 1 Volt equals 1 g, or 9.81 m/s^2.

⚠ **CAUTION: The accelerometer readings can be misleading and lead to unexpected results. Please use caution when using them as they are generally used as indicators.**

3.3. Specifications

The main specifications of the Shake Table II are given in Table 4. See Reference [2] for UPM-180-25B specifications and Reference [4] for a complete listing of the DC motor characteristics.

Parameter	*Matlab Notation*	*Parameter Description*	*SI Value*	*Units*	*IM Value*	*Units*
R_m	Rm	Motor armature resistance.	2.94	ohm		
K_t	Kt	Motor current-torque constant.	0.360	N.m/A	3.2	lb.in/A
K_m	Km	Motor back-emf constant.	0.2034	V/(rad/s)	23.4	V/k_{rpm}
P_b	Pb	Ball-screw pitch.	0.0127	m/rev	0.5	in/rev
M_p	Mp	Preload mass.	7.74	kg	17.1	lb
M_{l_max}	Ml_max	Maximum total load mass.	15.0	kg	33.0	lb
M_s	Ms	Mass of Shake Table II system.	27.2	kg	60.0	lb
		Dimension of top stage.	0.46 $\times$0.46	m^2	18.0 $\times$18.0	in^2
		Dimension of bottom stage.	0.61 $\times$0.46	m^2	24.0 $\times$18.0	in^2
		Height from bottom to top stage.	12.4	cm	4.875	in
x_{max}	P_MAX	Maximum stroke position.	76.2	mm	3.0	in
v_{max}	VEL_MAX	Maximum linear velocity of stage.	664.9	mm/s	26.18	in/s
F_{max}	F_MAX	Maximum linear force of stage.	708.7	N	159.3	lb
a_{max}	ACC_MAX	Maximum linear acceleration of stage for 0 kg load.	24.5	m/s^2		
g_{max}	G_MAX	Maximum linear acceleration of stage for 0 kg load.	2.50	g		
K_{ENC}	K_ENC	Encoder sensitivity gain	3.1006	µm/count	1.22E-004	in/count
K_{ACC}	K_ACC	Accelerometer sensitivity gain	-1	g/V		
		Dynamic load capacity of ball nut.	12000	N	2697.6	lb
		Life expectancy of ball nut at full load.	6.35E+008	m	2.50E+010	in
		Life expectancy of linear bearing.	6.35E+006	m	2.50E+008	in
		Load carrying capacity of linear bearings.	131.5	kg	290	lb

Table 4: Shake Table II specifications.

4. System Setup

To setup this experiment, the following hardware and software are required:

- ✔ **Power Amplifier:** Quanser UPM 180-25B, as detailed in Reference [2].
- ✔ **Data Acquisition Board:** Quanser Q4 or Q8 board. See Reference [1] for details.
- ✔ **Shake Table II Plant:** Quanser Shake Table II, as shown in Figure 1 above.
- ✔ **Real-Time Control Software:** WinCon-RTX configuration detailed in Reference [3].

Follow these steps to setup the Shake Table II system:

1. Install the Quanser Q4/Q8 board in a PC as described in Reference [1]. Reference [1] also provides a detailed description of the Q4/Q8 board.

⚠ **CAUTION: In many cases a PC is shipped with the STII system that is already setup with WinCon and either a Q4 or Q8 board.** In that case, the Q4/Q8 board does not need to be installed..

2. Install the WinCon control software on the PC and its associated programs as described in Reference [10]. Also see Section 4.1 for a listing of the necessary software needed depending on whether the *basic* or *advanced* configuration is to be setup.

⚠ **CAUTION: In many cases a PC is shipped with the STII system that is already setup with WinCon.** In that case, WinCon does not need to be installed.

3. Connect the Quanser UPM-180-25B and the Shake Table II to the Q4/Q8 data-acquisition system as explained in Section 4.2. The Quanser UPM-180-25B is the power amplifier used to drive the shake table motor and is described in Reference [2]

4.1. Software Requirements

There are two system configurations: **basic** and **advanced**. The *basic* configuration only enables users to run previously made WinCon controllers. It does not let users create or modify new ones as in the *advanced* configuration. Further, the *advanced* configuration enables users to perform more advanced analysis such as finding the FFT of a signal.

4.1.1. Basic Configuration

As already mentioned, the *basic* setup allows users to run the previously made WinCon controllers that are supplied with the Shake Table II CD. For example, users can load the *q_sine.wcp* file with WinCon to make the table track a sine wave. In this system configuration however, the functionality of the existing controllers cannot be modified and new controllers cannot be created. Thus a new controller that makes the table track a sawtooth wave command could not be constructed.

Software components for the *basic* configuration:

- ✔ Windows 2000/XP
- ✔ RTX
- ✔ WinCon

See Reference [10] for details on the compatible Windows and RTX versions needed to run WinCon.

4.1.2. Advanced Configuration

In the *advanced* setup, users can run the previously constructed WinCon controllers. In addition, users gain the ability to modify existing and create new WinCon controllers. The Matlab/Simulink package along with Visual Studio .NET is required for this. Here is the necessary software components for the *advanced* configuration:

- ✔ Windows 2000/XP
- ✔ RTX
- ✔ WinCon
- ✔ Matlab loaded with the following:
  - ✔ Simulink
  - ✔ Real-time Workshop (RTW)
- ✔ Visual Studio .NET

See Reference [10] for details on the compatible Windows, RTX, Matlab/Simulink, and Visual Studio .NET versions needed to run WinCon.

4.2. Hardware Setup

The different cables used to connect the various components of the shake table system is described in Section 4.2.1. Section 4.2.2 explains how to connect the Quanser Q8 Extended Terminal Board to either the Quanser Q4 or Q8 data acquisition card. In Section 4.2.3, the typical connections between the Q4 or Q8 board, the UPM-180-25B device, and the Shake Table II are described.

4.2.1. Cable Nomenclature

The various connector cables that are provided with the Shake Table II system are listed in Table 5. If additional system were ordered, such as the AMD-1 or AMD-2 (see references [5] and [6]), then other cables not listed Table 5 will have been supplied.

Cable	***Description***
 *Figure 5: "Motor" cable.*	The "Motor" cable corresponds to the 3-phase motor power leads. This cable is designed to connect from the Quanser's Universal Power Module model 180-25B (i.e. the output of the power module after signal amplification) to the brushless DC motor of the shake table.
 *Figure 6: "To Device" cable*	The "To Device" cable is a DB15 cable that connects the shake table circuit board to the UPM. It carries to the UPM the three limit sensors' signals and the motor encoder signals. It also supplies the DC power required by the different sensors.
 *Figure 7: "From MultiQ" cable.*	The "From MultiQ" 25-pin parallel cable connects the UPM to the data acquisition card terminal board. It is compatible with Quanser's quick-connect system. It carries the motor encoder signals, limit sensor signals, calibrate signal, and the S1, S2, S3, and S4 analog signals from the UPM. From the DAC, the cable carries the control signal (to be amplified and sent to the motor) as well as the calibrate and enable digital signals.
 *Figure 8: "Emergency Stop" cable.*	The "Emergency Stop" cable has a 6-pin-mini-DIN connector that connects to the side of the UPM. The UPM is enabled when the safety pushbutton switch is not pressed.

Cable	*Description*
 *Figure 9: "From Analog Sensors" cable.*	The "From Analog Sensors" cable is a 6-pin-mini-DIN-to-6-pin-mini-DIN cable that can be used to connect any potential plant sensor to the UPM such as accelerometers. It can provide a ±12VDC bias to analog sensors and carry their voltage signals to the DAC terminal board via the UPM.

Table 5: Cable nomenclature.

4.2.2. Connecting the Q8 Extended Terminal Board

Before wiring the ST II system, the Q4 or Q8 data-acquisition card must first be installed and connected to Q8 Extended Terminal Board. This terminal board is made specifically to interface with the Quanser UPM-180-25B device and is different then the standard terminal boards used.

If not already done so, see Reference [1] for instructions on how to install the Q4 or Q8 hardware-in-the-loop board in your PC. Then, follow these instructions to connect the Q4 or Q8 hardware-in-the-loop board to the Q8 Extended Terminal Board:

1. Ensure that the PC is powered off and that you are grounded.
2. Connect the ribbon cable labeled **J3** into the **Cable 3** connector on the Extended Terminal Board. Cable 3 is the shortest cable. In a tower PC, it will be the topmost cable where it comes out of the PC.

CAUTION: The red line on the ribbon cable should be closest to the "Table X" and "Table Y" parallel input connectors on the terminal board. The connectors have a tab such that they only go in one way.

3. Table 6 summarizes the connections between the Q4 and Q8 HIL board and the Q8 Extended Terminal Board. If using a Q8 control board, connect the **J2** ribbon cable from the Q8 into the **Cable 2** connector on the Q8 Extended Terminal Board. Cable 2 is the second shortest cable. In a tower unit, it is the middle cable where the ribbon cables exit the PC. If using a Q4 control board, there is no J2 cable and the Cable 2 connector on the terminal board is left unused.
4. Connect the **J1** ribbon cable to the **Cable 1** connector on the Q8 Extended Terminal Board. This is the longest ribbon cable.
5. With the terminal board sitting on top of the tower unit, the ribbon cables should not be twisted and should all lie neatly on top of one another. The cables are slightly offset from one another on the terminal board to match the offset of the connectors on the data acquisition card. The text on the terminal board should face the front of the computer.
6. Use the ribbon cable clamp provided to secure the ribbon cables together. The clamp comes with a peel-and-stick base so that you can mount the clamp to a clean surface, such as the top of your PC. Put the cables in the clamp before mounting it. If you do not wish to mount the clamp, then do not remove the peel-and-stick paper. Use of the clamp is unnecessary, but helps to keep your Q8 data acquisition system neat and tidy.

As mentioned in the procedure, in the Q4 DAQ board setup there is no **J2** ribbon cable. As a result, the **Cable 2** connector on Q8 Extended Terminal Board is not used.

Quanser HIL Board	*Connections to Q8 Extended Terminal Board*
Q8	J1 -> CHANNEL 1 J2 -> CHANNEL 2 J3 -> CHANNEL 3
Q4	J1 -> CHANNEL 1 J3 -> CHANNEL 3

Table 6: Ribbon cable connections between Quanser Q4/Q8 HIL board and Q8 Extended Terminal Board.

See Reference [1] for instruction on how to install the necessary drivers for the Q4 or Q8 board. Once the Q4/Q8 has been properly tested, you can proceed to Section 4.2.3 and wire the ST II system.

4.2.3. Shake Table II Wiring Procedure

The procedure in Section 4.2.3.1 explains in detail how to connect the Shake Table II system to run experiments. Section 4.2.3.2 provides a brief summary of the required connections.

4.2.3.1. Detailed Wiring Procedure

This section describes in detail how to connect the Shake Table II, UPM-180-25B and Q8 Extended Terminal Board together. The connections are illustrated in figures 10, 11, and 12 with a corresponding identification number. Follow these steps to wire the ST II system:

1. **Connect cable #1** from the "Table X" connector on the Quanser Q8 Extended Terminal Board, shown in Figure 10, to the "From MultiQ" connector on the Quanser UPM-180-25B, as depicted Figure 11. This connection is done using the parallel cable shown in Figure 7. See Appendix B for a listing of all the signals that are passed through this cable.
2. **Connect cable #2** from the "To Device" connector located on the UPM front panel, as shown in Figure 11, to the ST II circuit board illustrated in Figure 12. This cable used in this connection is the DB15 cable described in Table 5 and pictured in Figure 6. It carries all three proximity sensor signals, the motor encoder signals, and the brushless motor hall sensor signals to the UPM-180-25B unit. The motor encoder is used to calculate the linear position of the cart and is denoted by the variable x.
3. **Connect cable #3** into the side of the UPM, as presented in Figure 11. Cable #3 is the "Emergency Stop" cable described in Table 5 and illustrated in Figure 8. The UPM is active if and only if the remote E-Stop switch is *depressed*.
4. **Connect cable #4** from the "Motor" connector located on the UPM front panel, as depicted in Figure 11, to the "Motor" connector on the shake table, as shown Figure 12. The motor leads connector is component #13 in Figure 3. This connection is done using the "Motor" cable described in Table 5 and illustrated in Figure 5. It carries the required 3-phase power to the

brushless motor.

5. **Connect cable #5** from the analog connector on the accelerometer mounted on the shake table , see Figure 12, to the “S1” connector on the front panel of the UPM-180-25B. **Ensure the UPM is not powered when making this connection.** It carries the acceleration measured by the accelerometer.
6. Go through the ST II test procedure in Section 5.3.

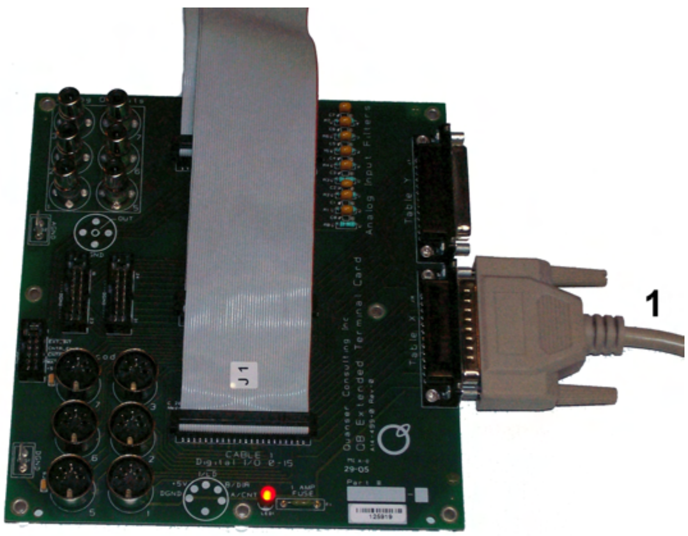

Figure 10: Connections on the Q8 Extended Terminal Board.

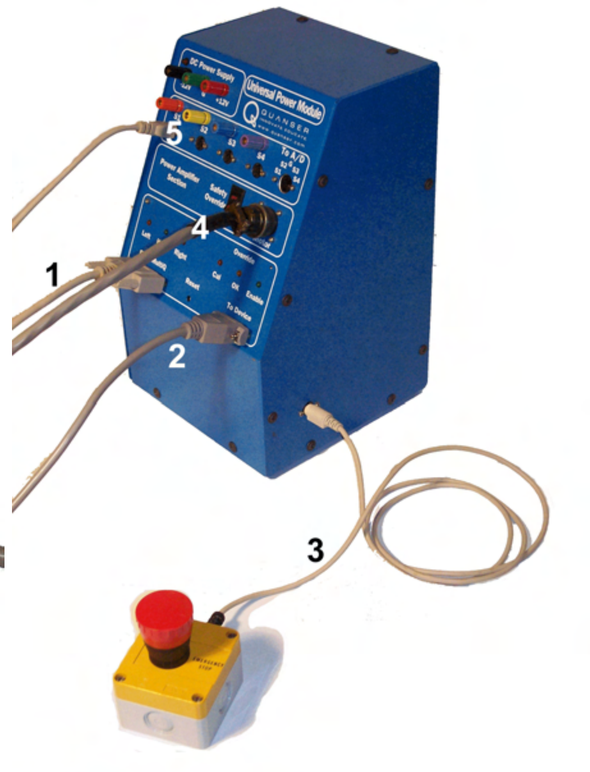

Figure 11: Connections on UPM-180-25B.

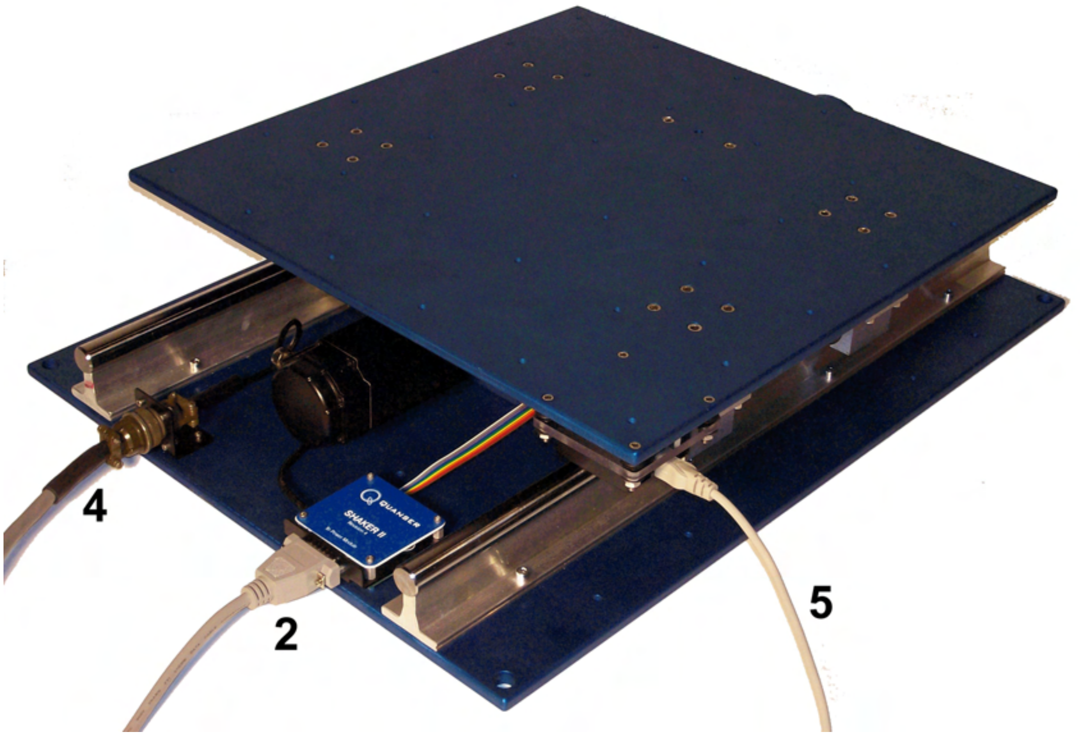

Figure 12: Connections of the Shake Table II device.

4.2.3.2. Wiring Summary

See Table 7 below for a summary of the Shake Table II connections.

Cable #	Cable Type	From	To	Function
1	25-pin Parallel Cable	"Table X" on the Terminal Board	"From MultiQ" on the blue UPM-180-25B	Drives the amplifier to move the stage and receives the accelerometer, stage encoder, calibration, and limit detector signals from UPM.
2	15-pin Parallel Cable	"To Device" on the blue UPM-180-25B	Circuit board on the Shake Table II	Receives the encoder and limit detector signals from the shake table.
3	"Emergency Stop" Cable	E-Stop Switch	UPM E-Stop Connector	Carries the emergency stop signal.
4	4-pin Motor Cable	"Motor" Connector on the	Motor connector on the Shake	Connects the shake table motor leads to the amplifier on the UPM.

Cable #	Cable Type	From	To	Function
		UPM-180-25B	Table II	
5	Analog Cable: 6-pin-mini-DIN to 6-pin-mini-DIN	"S1" Connector on the on the UPM-180-25B	Accelerometer on the Shake Table II	Carries the acceleration signal of the stage to the UPM.

Table 7: Shake Table II wiring summary.

5. Performing Shake Table II Experiments with WinCon

Section 5.1 briefly describes the directory structure of the Shake Table II CD. All users, both those with the *basic* and *advanced* system configurations, should go through the standard experiments listed in Section 5.2 and the procedure in Section 5.3 to test the Shake Table II connections.

5.1. Overview of Shake Table II CD

The *Shake Table II CD* supplied with the system contains various files. There are three folders on the shake table CD that correspond to three different system configurations and they are explained in Table 8.

Folder Name	Description
STII	Contains this manual as well as controllers to run the Shake Table II system by itself.
AMD	Has manuals and controllers for using the Quanser Active Mass Damper by itself. The active mass damper, i.e. The linear cart on top of the building, perturbs the building and then dampens for the building oscillations. The one floor structure is called AMD-1 and is described in Reference [5] and the two floor structure is called the AMD-2 device and is presented in Reference [6].
STII+AMD	Contains manuals and controllers to use the Quanser AMD-1, AMD-2, and 2xAMD-1 systems when mounted on top of the Shake Table II system. See Reference [7], [8], and [9] for more information on the STII+AMD-1, STII+AMD-2, and STII+2xAMD-1 systems. In this configuration, the shake table provides the base motions to perturb the building while the active mass does the vibration dampening.

Table 8: Description of main folder on the Shake Table II CD.

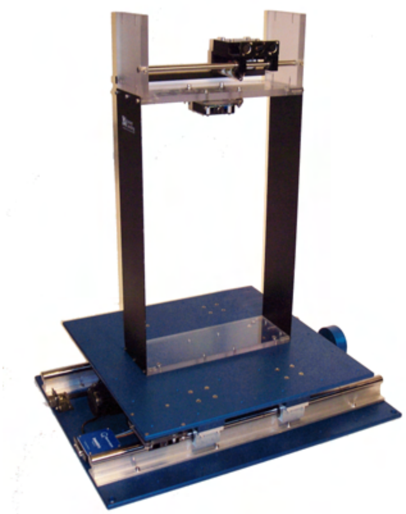

Figure 13: Shake Table II with the Quanser AMD-1 system.

Figure 14: Shake Table II with the Quanser AMD-2 system.

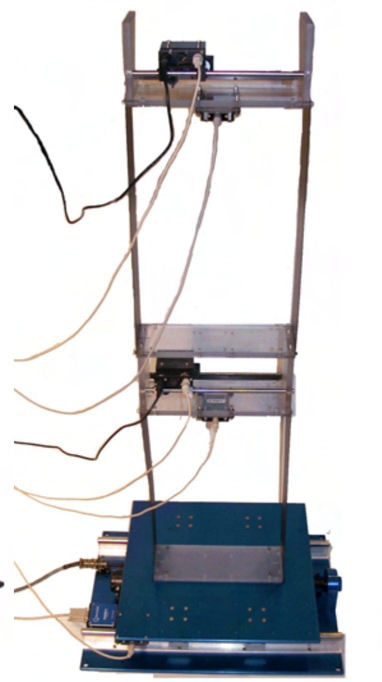

Figure 15: Shake Table II with the Quanser 2xAMD-1 system.

The *STII* folder on the *Shake Table II CD* has the following directory structure:

\STII
.... *\Manual*
.... *\UPM Manual*
.... *\Specifications*
.... *\Lab Files*
.... *\q4*
.... *\wcp*
.... *\mdl*
.... *\q8*
.... *\wcp*
.... \mdl

The *Manual* folder contains documentation such as this Shake Table II User Manual, the *Universal* Power Module User Manual, and the motor specification sheet. The *Lab Files* directory includes previously compiled WinCon controllers that were built for the Q4 and Q8 boards, in the *wcp* folder, as well as the source Simulink models that were used to create those WinCon controllers, in the *mdl* folder. The *wcp* name stands for WinCon Project and the *mdl* folder name denotes Simulink Model. Choose the lab files depending on the whether the Quanser Q4 or Q8 HIL board is connected to the ST II.

5.2. Standard ST II Experiments

There are five standard controllers for the Shake Table II: initializing the UPM, calibrating the stage to the home position, running a sine wave, running a sine sweep, and running an earthquake. These standard experiments are contained in the *wcp* folder of the Shake Table II CD. The WinCon Project file name for each experiment is listed in Table 9 below. It also includes a description of the experiment (what WinCon Project does when ran) and the section number where the procedure to run the WinCon Project is given. Only the *basic* configuration is required to run these experiments (Matlab is not needed).

File Name	*Description*	*Section Number*
q_boot_upm_zz.wcp	Initializes the UPM-180-25B to make the amplifier ready-to-be-enabled. This has to be done prior to performing any of the ST II experiments.	5.2.1
q_cal_zz.wcp	Returns the stage to the *home* position. The stage should be at the home position before running any of the experiments.	5.2.2
q_sine_zz.wcp	Position of the stage tracks a sine wave with an amplitude and frequency set by the user.	5.2.5
q_sweep_zz.wcp	Sends a sine sweep to the shake table for generating the frequency response.	5.2.4
q_quake_kobe_zz.wcp	Kobe earthquake.	5.2.5
q_quake_northridge_zz.wcp	Northridge earthquake.	5.2.5
start_exp.m	Opens a graphical user interface that can be used to open the various WinCon Projects. **Matlab is needed to run this**.	5.2.7

Table 9: Files supplied in the "wcp" folder of the Shake Table II CD.

In addition, see Section 5.2.6 for more information on using scopes. It lists a description of all the scopes available for viewing, explains how to open new scopes, and how to adjust the time axis of a plot.

5.2.1. Initializing UPM

When the blue UPM-180-25B is first powered, the *Left* and *Right* LEDs located on its front panel should be blinking. To stop the blinking and initialize the UPM-180-25B device, run the *q_boot_upm_zz.wcp* project as instructed in the Reference [2] in Section 3.5.1. The steps are summarized here:

1. Ensure that the *Safety Override* switch, located on the UPM front panel, is OFF.

2. Connect the *Emergency Stop* cable to the connector on the side panel of the UPM.
3. Rotate the knob in the counter-clockwise direction until it is released in the upright position. The amplifier cannot drive the motor when the red knob is pushed in.
4. After power up, the *Left* and *Right* LEDs on the UPM front panel should be blinking. If the lights are NOT flashing consult Reference [2].
5. Load the WinCon Server software (typically placed under Quanser | WinCon in the Windows START menu).
6. Open the *q_boot_upm_zz.wcp* WinCon project that is supplied. The *zz* suffix denotes the type of data-acquisition card being used. For example, if *zz* is *q4* then the file is meant to be used with the Quanser Q4 control board. Alternatively, if *zz* is *q8* then the file is to be used with the Quanser Q8 data-acquisition system.
7. Run the initialization controller by clicking on the green START button in the WinCon Server window.
8. The *Left* and *Right* LEDs should stop flashing and the window shown in Figure 16 should be prompted. If the LEDs are no longer blinking, then the UPM amplifier is ready to be used for the various ST II experiments.

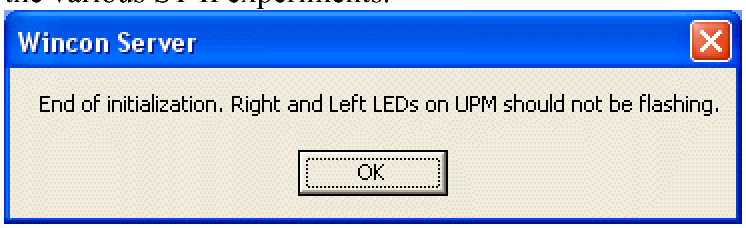

Figure 16: Message prompted after running UPM boot WCP.

5.2.2. Calibrating Stage

Before running any of the experiments the stage of the Shake Table II should be in the mid-stroke position. This position is called the *Home* position because the Home limit sensor is triggered when the stage is centered.

Follow this procedure to calibrate the stage to the *Home* position:

1. Ensure the UPM180-25B has been initialized as instructed in Section 5.2.1.
2. Load the WinCon Server software (usually under Quanser | WinCon in the Windows START menu).
3. In the WinCon Server window, click on File | Open and select the WinCon Project file *q_cal_zz.wcp*.
4. Click on the green *START* button in the *WinCon Server* window.

> **ATTENTION: PRESS DOWN on the RED BUTTON of the E-Stop switch in case of emergency.** If something goes wrong during an experiment, pressing the red button of the E-Stop switch disables the amplifier and shuts off the DC motor power.

5. On the front panel of the UPM, the LEDs *Cal*, *OK*, and *Enable* LEDs should all be lit and the stage should begin moving. If the Left or Right limit sensor was already triggered, then the stage begins to immediately move towards the center. If no limit switch was initially triggered, then the stage will begins to move towards Left limit sensor. Once the Left limit sensor is hit, the

stage reverses its direction and begins moving towards the mid-stroke position. The stage stops moving when the *Home* limit switch is triggered (the *Home* LED on the UPM will go ON). When complete, the message shown in Figure 17 is displayed.

Figure 17: Messaged prompted after running calibration WCP.

6. Alternatively, the knurled knob at the end of the table can be used to manually return the table to its home position. The *Home* LED on the UPM will be lit when this position is reached.
7. If the table is not moving consult the troubleshooting guide at the end of this manual.

When the UPM is placed in the calibration mode, i.e. the *Cal*, *OK*, and *Enable* LEDs are lit, the amplifier remains enabled when the *Left* or *Right* proximity sensor are triggered but is disabled when the *Home* limit sensor is activated. Normally and for all the other experiments, the amplifier is disabled when the *Left* or *Right* sensor is triggered.

CAUTION: If the stage remains motionless when running the *q_cal_zz* controller (when not at *home* position) try running the *q_boot_upm* project again. Thus stop the *q_cal_zz* controller, go through the procedure in Section 5.2.1, and then run *q_cal_zz* again as explained above.

5.2.3. Sine Wave

In this experiment, the position of the Shake Table II stage tracks a user-specified sine wave signal. The user can specify the amplitude and frequency of the sine wave.

Follow these steps to run the sine wave project:

1. Make sure the amplifier has been initialized as discussed in Section 5.2.1.
2. **CAUTION: Ensure table is at *HOME* position before running this experiment!** Otherwise the experiment may stop prematurely because the table reached the left or right limit sensors. If the *Home* LED on the front panel of the blue UPM-180-25B is **not** lit, then go through the calibration procedure in Section 5.2.2.
3. Load the WinCon Server software (usually under Quanser | WinCon in the Windows START menu).
4. In the WinCon Server window, click on File | Open and select the WinCon Project file *q_sine_zz.wcp*. The project contains the control panel shown in Figure 18 and the *x (m)* scope, depicted in Figure 19 with results. The control panel has a vertical slider to change the amplitude of the sine wave position command and a knob to control the frequency of the signal.

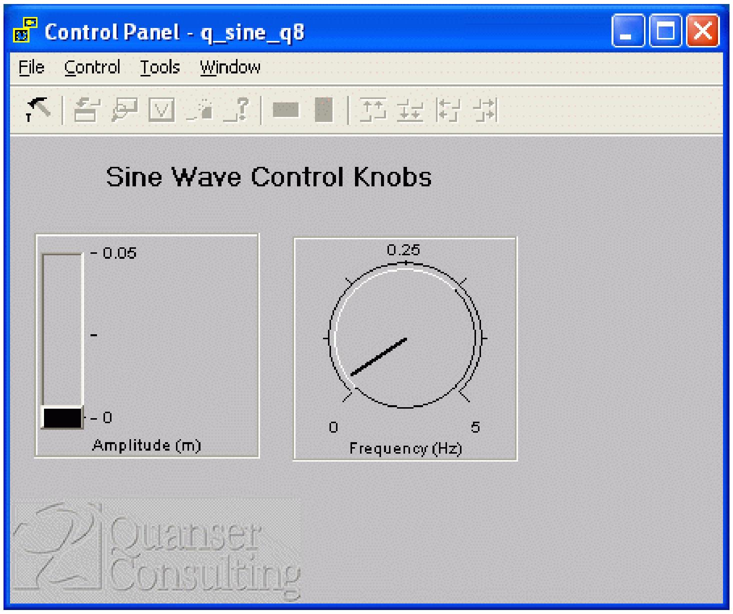

Figure 18: Front panel of sine wave WCP.

5. Click on the green *START* button in the *WinCon Server* window. The *x (m)* scope should begin plotting data and the START button in the WinCon Server window should now be a red STOP button. Since the amplitude in the control panel is set to 0, the table is not commanded any position and therefore should not be moving.

ATTENTION: PRESS DOWN on the RED BUTTON of the E-Stop switch in case of emergency. If something goes wrong during an experiment, pressing the red button of the E-Stop switch disables the amplifier and shuts off the DC motor power.

6. The *Enable* and *OK* LEDs on the UPM should be lit. Consult the troubleshooting guide if this is not the case.
7. Move the vertical slider in the Control Panel to 0.02 meters. The stage should begin tracking a sine wave of 20 cm at a frequency of 0.5 Hz. The *x (m)* scope displays the desired or commanded position set by the user and the resulting measured position. Figure 19 illustrates the results when the sine wave frequency is changed from 0.5 Hz to 1.0 Hz at around the 2 second mark. As shown, both the desired and measured responses are almost identical (however, there is always a small discrepancy due to the sampling delay).

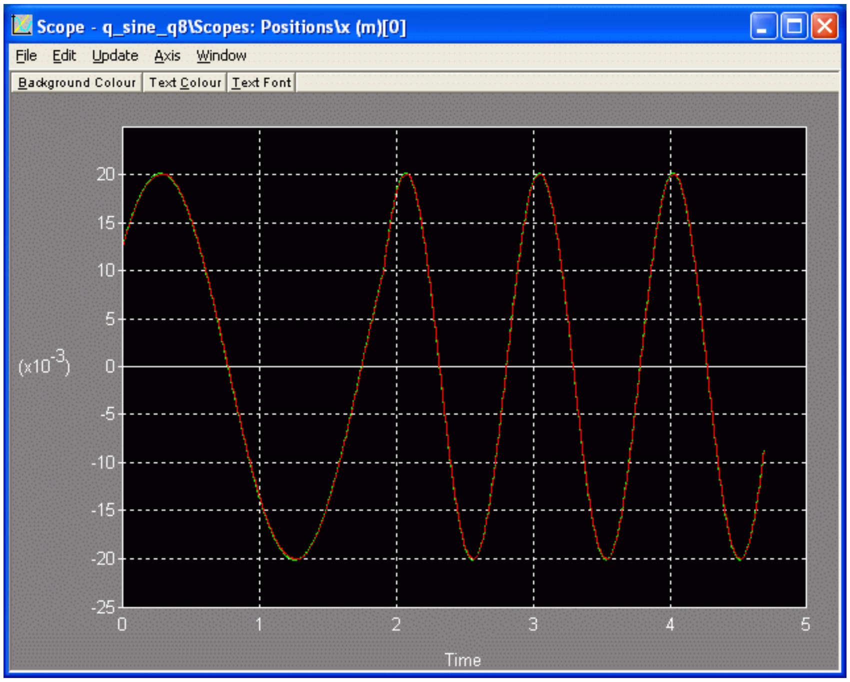

Figure 19: The x (m) scope when running the q_sine_q8 controller.

8. When finished set the *Amplitude (m)* control knob to 0 m, in order to bring the stage back to *Home* position.
9. Click on the red *STOP* button in the *WinCon Server* window to stop running the sine wave controller.
10. Shut off the UPM-180-25B power.

5.2.4. Sine Sweep

The sine sweep, also known as a chirp signal, is a sine wave with a fixed amplitude that increases in frequency as time progresses. In this experiment, the stage of the Shake Table II tracks a given sine sweep that increases from 1 Hz to 15 Hz in 30 seconds. By default the sine amplitude is 0.2 cm but this can be varied though the control panel. Typically the sine sweep is used to find the frequency response of a structure that is mounted on the table stage (need the *advanced* package for this).

Follow this procedure to run the sine sweep controller:

1. Ensure the amplifier has been initialized as discussed in Section 5.2.1.
2. **ATTENTION: Ensure table is at *HOME* position before running this experiment!** Otherwise the experiment may stop prematurely because the table reached the left or right limit sensors. If the *Home* LED on the front panel of the blue UPM-180-25B is **not** lit, then go through the calibration procedure in Section 5.2.2.
3. Load the WinCon Server software (usually under Quanser | WinCon in the Windows START menu).
4. In the WinCon Server window, click on File | Open and select the WinCon Project file

q_sweep_zz.wcp. The project contains the control panel shown in Figure 20 and the scope a_tbl (g) pictured in Figure 21 with data. With the vertical slider in the control panel, the user can change the amplitude of the sine sweep signal between 0 and 3 cm. The *a_tbl (g)* scope displays the acceleration measured by the table accelerometer in gravitational units, *g*.

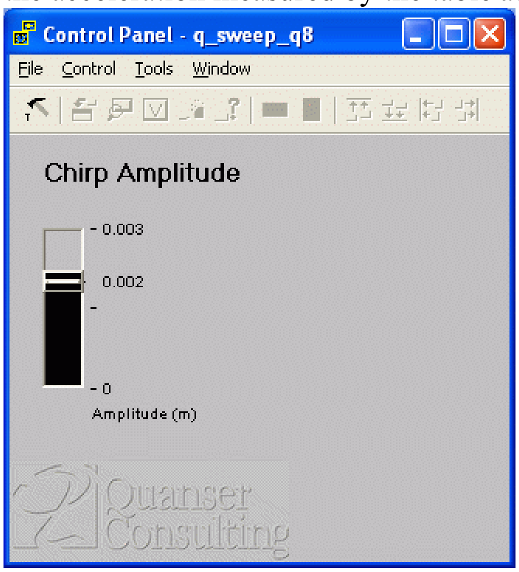

Figure 20: Control panel for sine sweep project.

5. Click on the green *START* button in the *WinCon Server* window to start the controller.

ATTENTION: PRESS DOWN on the RED BUTTON of the E-Stop switch in case of emergency. If something goes wrong during an experiment, pressing the red button of the E-Stop switch disables the amplifier and shuts off the DC motor power.

At first, the stage moves back and forth slowly as it tracks the sine wave and the *a_tbl (g)* scope begins plotting acceleration data. The stage will begin oscillating faster and faster as the frequency of the position command increases over time. The sine sweep lasts 30 seconds and is automatically restarted once the duration is reached. See Figure 21 for a typical acceleration measurement after running the sine sweep on the shake table.

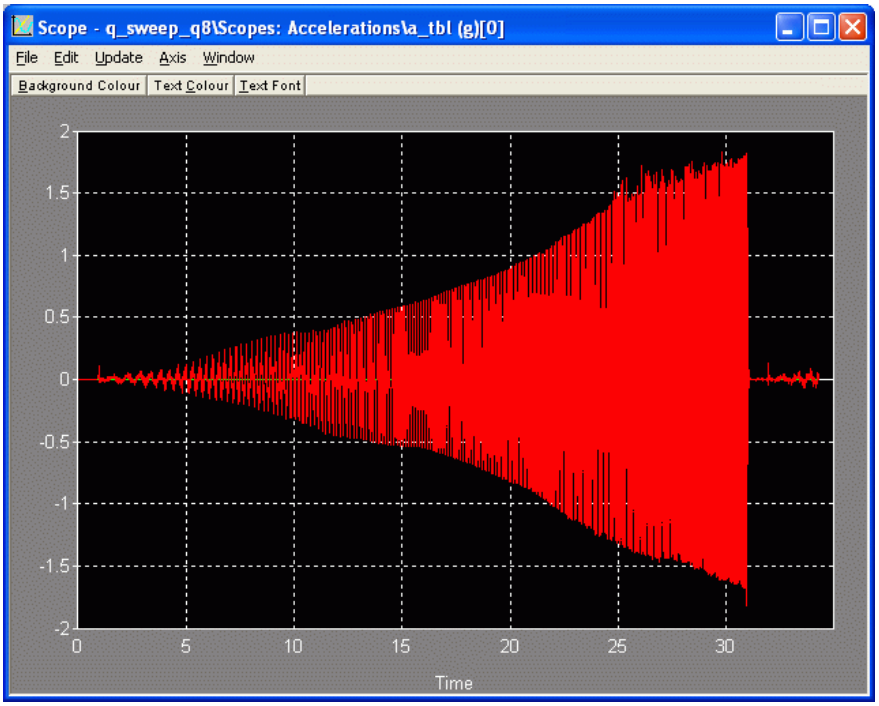

Figure 21: The a_tbl (g) scope after running the q_sweep_q8 controller.

6. Click on the red *STOP* button in the *WinCon Server* window to stop running the sine sweep controller.
7. Shut off the UPM-180-25B power.

5.2.5. Sample Earthquake

Recorded earthquake data that was collected when actual earthquake occurred can be scaled down and ran on the shake table. Two standard historical earthquakes have been supplied for the user: Kobe and Northridge.

Follow this procedure to run a sample earthquake:

1. Ensure the amplifier has been initialized as discussed in Section 5.2.1.
2. **ATTENTION: Ensure table is at *HOME* position before running this experiment!** Otherwise the experiment may stop prematurely because the table reached the left or right limit sensors. If the *Home* LED on the front panel of the blue UPM-180-25B is **not** lit, then go through the calibration procedure in Section 5.2.2.
3. Load the WinCon Server software (usually under Quanser | WinCon in the Windows START menu).
4. In the WinCon Server window, click on File | Open and select either the *q_kobe_zz.wcp* or *q_northridge_zz.wcp* WinCon Project files to run the Kobe or Northridge earthquakes on the table. The projects include the *a_tbl (g)* scope, depicted in Figure 22 after running the experiment, that displays the desired acceleration, which is the actual recorded acceleration of the tremor, in green and the acceleration measured by the table accelerometer in red. Both accelerations are given in gravitational units, *g*, and should be similar.

5. Click on the green *START* button in the *WinCon Server* window.

PRESS DOWN on the RED BUTTON of the E-Stop switch in case of emergency. If something goes wrong during an experiment, pressing the red button of the E-Stop switch disables the amplifier and shuts off the DC motor power.

The stage should begin moving back and forth and the accelerations in the *a_tbl (g)* scope should start plotting. The end result is shown in Figure 22.

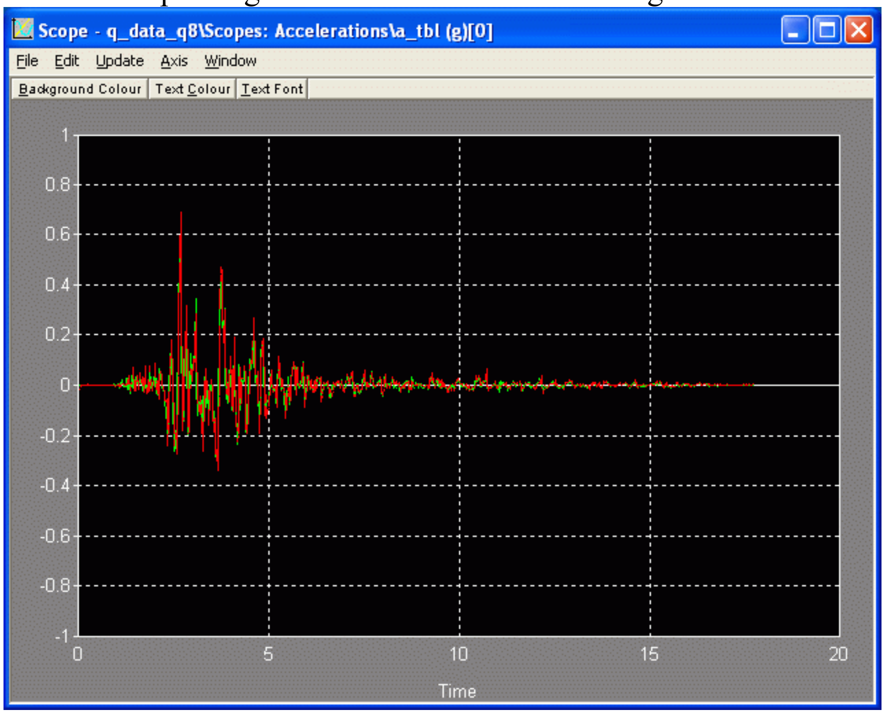

Figure 22: Acceleration measurements plotted in a_tbl (g) scope after running Northridge earthquake.

6. WinCon stops automatically when the earthquake duration has been reached.
7. Shut off the UPM-180-25B power

5.2.6. Working with Scopes

Section 5.2.6.1 describes all the scopes available for viewing and Section 5.2.6.2 explains how to open a new scope (that was perhaps not already opened when loading the WinCon Project). The procedure to decrease or increase the time scale of a scope is described in Section 5.2.6.3.

5.2.6.1. Scope Descriptions

With the exception of the *q_boot_upm_zz*, all the supplied ST II controllers include the scopes listed in Table 10.

Matlab Name	*Variable Name*	*Description*
x (m)	x	Displays two plots: (1) green plot is the desired stage position in meters (2) red plot is the measured stage position in meters
x (in)	x	Same as above except position shown in inches.
V (m/s)	v_x	Measured stage velocity in meters per second calculated from position measurement.
V (in/s)	v_x	Same as above except in inches per second.
x_ddot (g)	$a_{x,enc}$	Acceleration of stage calculated from the position measurement given in gravitational units, *g*.
x_ddot (m/s^2)	$a_{x,enc}$	Same as above except acceleration shown in meters per second squared, m/s^2.
Im (A)	I_m	Input motor current in amperes.
a_tbl (g)	a_g	Displays two plots: (1) green plot is the stage acceleration measured by the accelerometer (2) red plot is the desired acceleration used (set to 0 when using *q_sine_zz* or *q_sweep_zz* controllers).
a_tbl (m/s^2)	a_g	Same as above except acceleration shown in meters per second squared, m/s^2.
a_f1 (g)	a_{f1}	Acceleration of the stage measured by accelerometer #1 in gravitational units, *g*. It is denoted *a_f1* because, typically, it is used with the accelerometer mounted on the first floor of the Quanser AMD-1 or AMD-2 structure (see Reference [5] and [6] for more information).
a_f1 (m/s^2)	a_{f1}	Same as above except acceleration shown in meters per second squared, m/s^2.
a_f2 (g)	a_{f2}	Acceleration of the stage measured by accelerometer #2 in gravitational units, *g*. It is denoted *a_f2* because, typically, it is used with the accelerometer mounted on the second floor of a Quanser AMD-2 structure (see Reference [6] for more information).
a_f2 (m/s^2)	a_{f2}	Same as above except acceleration shown in meters per second squared, m/s^2.

Table 10: Description of the predefined scopes in the ST II WinCon Projects.

As described in Table 10, the *x (m)*, *x (in)*, *a_tbl (g)*, and *a_tbl (m/s2)* scopes display two variables of data. Most of the time, the desired and measured positions in the *x* scopes closely match one another and, as a result, the green (desired) and red (measured) plot traces will be almost directly on top of each

other.

The desired acceleration is only used in controllers with a previously defined trajectory, such as the *q_kobe_zz* or *q_northridge_zz* controllers. When running those experiments, the green desired acceleration trace and the red measured acceleration traces in the *a_tbl (g)*, and *a_tbl (m/s2)* scopes will closely match. However, when running the *q_sine_zz* or *q_sweep_zz* controllers the green desired acceleration scope is set to 0 because there is no desired acceleration defined (only the red measured signal will be shown).

5.2.6.2. Opening Additional Scopes

When opening a WinCon Project such as *q_sine_zz.wcp*, only the *x (m)* scope is loaded. If the user wishes to view, for instance, the acceleration measured by the stage accelerometer in *g* units, then the *a_tbl (g)* scopes has to be opened.

Follow these steps to open one of the scopes defined in Table 10

1. Load one of the supplied WinCon projects (except q_boot_upm or q_cal_zz) as described by the above procedures.
2. Click on the *Open plot* button in the WinCon Server window, as shown in Figure 23 below.

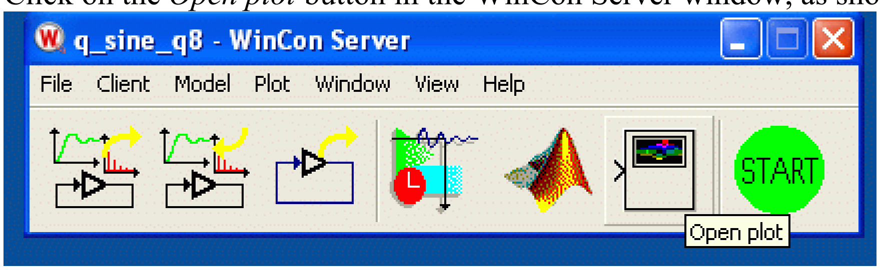

Figure 23: Open plot button in the WinCon Server window.

3. Select the variables to view. For example as illustrated in Figure 24, to view the velocity and acceleration of the stage place a check mark on the *v (m)* and *a_tbl (g)* items.

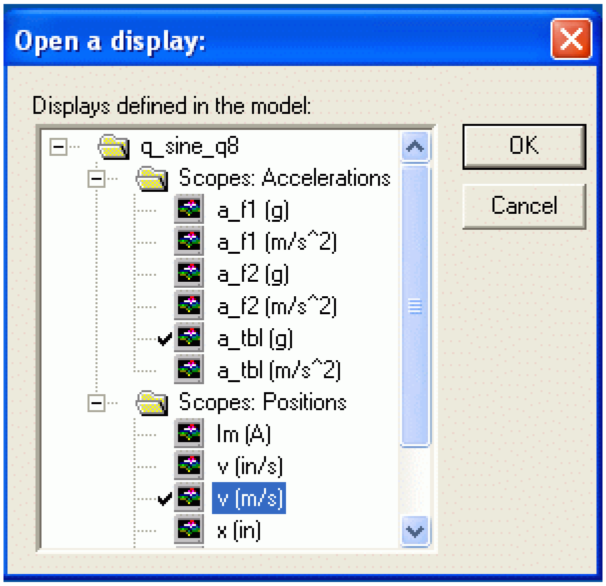

Figure 24: Selecting scopes to be opened.

4. Click on the *OK* button to load the scope(s).

5.2.6.3. Changing Time Scale of a Scope

By default, scopes have a time-scale of 5.0 seconds. The horizontal time-scale, or buffer size, of a scope can be changed in order to view data over a larger span of time or to "zoom up" on a response by decreasing the time-scale.

Follow this procedure to change the time buffer of an opened scope:

1. Select the *Update | Buffer...* item in the scope menu bar to load the *Select Buffer Size* window shown in Figure 25.

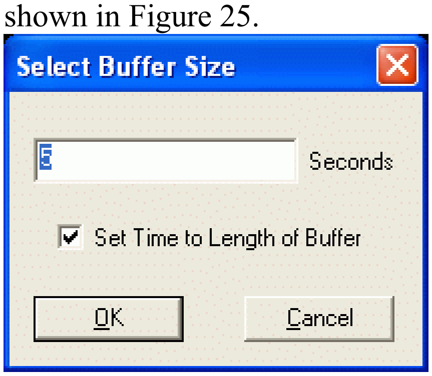

Figure 25: Changing scope time buffer window.

2. Enter a new time buffer. For example, if 10 seconds is entered instead of 5 then the scope will display 10 seconds of data instead of 5 seconds.
3. Click on the *OK* button to apply the changes.

5.2.7. Optional: Using the GUI

For users with the *Advanced* package, or at least those that have Matlab , the graphical user-interface shown in Figure 26 can be used to browse through the various supplied WinCon Projects.

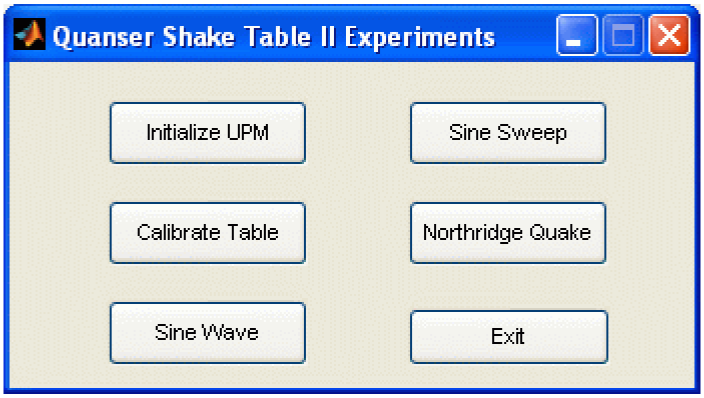

Figure 26: GUI for browsing through ST II WinCon controllers.

Follow this procedure to open the GUI:

1. Load Matlab
2. Through the *Current Directory* window, go to the *STII\Lab Files\zz\wcp* folder (where *zz* is q4 or q8) on your PC (which was copied from the ST II CD).
3. Run the *start_exp.m* Matlab script. The GUI shown in Figure 26 should load.
4. Click on a button to load the corresponding WinCon Project. For example, click on the *Sine Wave* button to load the sine controller that is explained in Section 5.2.3.
5. Click on the *EXIT* button to close the GUI.

5.3. ST II Test

This section goes through a procedure to test the Shake Table II hardware after it has been setup as dictated in Section 4. This method should be undergone before performing any of the standards experiments

Follow these steps to test the Shake Table II:

1. Verify that the system has been setup as instructed in Section 4.
2. Turn the blue UPM power ON. The Left and Right LEDs should be blinking. To stop the blinking and initialize the UPM-180-25B device, run the *q_boot_upm_zz* project as instructed in the Section 5.2.1. If the *Left* and *Right* LEDs stop blinking the UPM has been initialized. This also implies that WinCon has been properly installed and that the UPM and Q4/Q8 connection has been made properly. Move on to the next step if this test passed.
3. Run the *q_cal_zz* controller as detailed in Section 5.2.2 to center the stage. If this test works then the Shake Table II and UPM connections have been made properly and the user can continue to the next step.
4. Run the *q_sine_zz* controller explained in Section 5.2.3. If the table tracks the commanded sine wave then the system has been properly installed and is functioning properly.